(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 January 2001 (11.01.2001)

PCT

(10) International Publication Number
WO 01/02899 A2

(51) International Patent Classification[7]: G02F 1/00

(21) International Application Number: PCT/US00/17944

(22) International Filing Date: 29 June 2000 (29.06.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/142,003 1 July 1999 (01.07.1999) US

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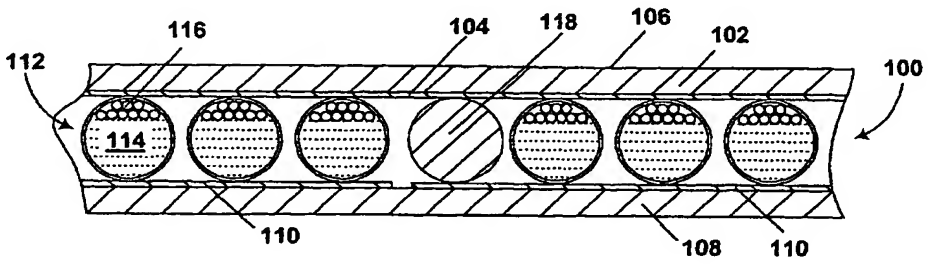
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *Without international search report and to be republished upon receipt of that report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ELECTROPHORETIC MEDIUM PROVIDED WITH SPACERS



(57) Abstract: An encapsulated electrophoretic medium comprises a layer of capsules, each of these capsules comprising a liquid and at least one particle disposed within the liquid and capable of movement upon application of an electric field to the medium. A plurality of spacers are dispersed among the capsules. The medium can be formed by coating a mixture of capsules and spacers on a substrate, or by first coating the capsules and thereafter incorporating the spacers into the layer of capsules.

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ELECTROPHORETIC MEDIUM PROVIDED WITH SPACERS

The present invention relates to an electrophoretic medium provided with spacers, and to an electrophoretic display incorporating such a medium.

Electrophoretic displays have been the subject of intense research and development for a number of years. Such displays can have attributes of good brightness and contrast, wide viewing angles, state bistability, and low power consumption when compared with liquid crystal displays. (The terms "bistable" and "bistability" are used herein in their conventional meaning in the art to refer to displays comprising display elements having first and second display states differing in at least one optical property, and such that after any given element has been driven, by means of an addressing pulse of finite duration, to assume either its first or second display state, after the addressing pulse has terminated, that state will persist for at least several times, for example at least four times, the minimum duration of the addressing pulse required to change the state of the display element.) Nevertheless, problems with the long-term image quality of these displays have prevented their widespread usage. For example, particles that make up electrophoretic displays tend to cluster and settle, resulting in inadequate service-life for these displays.

An encapsulated, electrophoretic display typically does not suffer from the clustering and settling failure mode of traditional electrophoretic devices and provides further advantages, such as the ability to print or coat the display on a wide variety of flexible and rigid substrates. (Use of the word "printing" is intended to include all forms of printing and coating, including, but without limitation: pre-metered coatings such as patch die coating, slot or extrusion coating, slide or cascade coating, curtain coating; roll coating such as knife over roll coating, forward and reverse roll coating; gravure coating; dip coating; spray coating; meniscus coating; spin coating; brush coating; air knife coating; silk screen printing processes; electrostatic printing processes; thermal printing processes; ink jet printing processes; and other similar

techniques.) Thus, the resulting display can be flexible. Further, because the display medium can be printed (using a variety of methods), the display itself can be made inexpensively.

One major reason why encapsulated electrophoretic displays can be produced inexpensively by printing processes is that the electrophoretic medium itself has substantial mechanical strength and cohesion; typically the individual capsules are bound together by a polymeric binder to increase the cohesion of the layer. Thus, not only can the display medium itself be printed, but as described in copending Application Serial No. 09/141,103 and the corresponding International Application No. PCT/US98/17735 (Publication No. WO 99/10768), an electrode may be formed by printing a conductive material directly on to the electrophoretic medium; alternatively, an electrode pre-formed on a substrate can be laminated on to the electrophoretic medium, which is able to withstand the heat and pressure required for such lamination without damage. In such printed or laminated structures, the mechanical strength and cohesion of the electrophoretic medium maintain the requisite spacing between the electrodes disposed on either side of the medium without any need for mechanical spacers or similar devices to control this spacing. Accordingly, if the electrodes (and any substrates attached thereto) are flexible, the encapsulated electrophoretic display can be curved or rolled without affecting the display qualities of the device; see, for example, Drzaic et al., "A Printed and Rollable Bistable Electronic Display SID (Society for Information Display) 98 Digest, page 1131 (1998), which illustrates a flexible encapsulated electrophoretic display being rolled around a pencil without damage.

Although, as described above, encapsulated electrophoretic media possess considerable mechanical strength and cohesion, it is of course important that none of the capsules in such displays be ruptured, since rupture of even a small number of capsules allows the internal phase of the capsules (this internal phase comprising the electrophoretic particles themselves and the liquid medium in which they are

suspended) to leak through the medium, thus adversely affecting the appearance of the display. It has now been found that, by providing spacers within such an encapsulated electrophoretic medium, the resistance of the medium to mechanical stresses can be increased, thereby enabling the medium to be used in applications, and under processing conditions, which would otherwise result in unacceptable capsule rupture.

In one aspect, this invention provides an encapsulated electrophoretic medium comprising a layer of capsules, each of these capsules comprising a liquid and at least one particle disposed within the liquid and capable of moving therethrough on application of an electric field to the medium. The medium is characterized by a plurality of spacers dispersed among the capsules.

In another aspect, this invention provides a method of forming an electrophoretic display; this method comprises (a) providing a substrate; and (b) providing, adjacent the substrate, an encapsulated electrophoretic medium comprising a layer of capsules, each of these capsules comprising a liquid and at least one particle disposed within the liquid and capable of moving therethrough on application of an electric field to the medium. The method is characterized by providing a plurality of spacers dispersed among the capsules.

Figures 1, 2 and 3 of the accompanying drawings are schematic cross-sections, taken perpendicular to the plane of the electrodes of the displays, through three different preferred encapsulated electrophoretic displays of the present invention. These drawings are not to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

As already mentioned, in the encapsulated electrophoretic medium of the present invention a plurality of spacers are dispersed among the capsules. These spacers serve to relieve some of the pressure which would otherwise be applied to the capsules when substantial pressures are placed upon the electrophoretic medium, thus enabling the medium to withstand, without capsule rupture, higher pressures than it would be able to withstand in the absence of the spacers.

It should be emphasized that the spacers used in the present medium serve an entirely different function than the spacers used in conventional liquid crystal displays. As already mentioned, an encapsulated electrophoretic medium possesses considerable mechanical strength and cohesion, and hence is well able to accurately control the spacing between its associated electrodes without the need for spacers. In contrast, in a conventional liquid crystal display the electro-optically active layer of liquid crystal is a true liquid and is incapable of itself maintaining any specific spacing between the layers of the display disposed on opposed sides of the liquid crystal layer. Furthermore, such a liquid crystal display requires the maintenance of a very small gap, typically about 2 to 7 μm, over the entire width of the display, which may be 12 inches (304 mm) or more. Since the operation of the liquid crystal display depends upon the liquid crystal rotating the plane of polarization of light, and this rotation is proportional to the thickness of the liquid crystal layer, the gap has to maintained with great accuracy. Even though liquid crystal displays are typically constructed using rigid glass plates, it is wholly impracticable to maintain the necessary spacing with sufficient accuracy over the whole width of the display without resorting to the use of spacers within the liquid crystal layer, since otherwise even modest pressure upon the surface of the display would be sufficient to cause enough change in the gap to produce substantial changes in the appearance of the display.

As an illustration of the difference in function between the spacers used in the present invention and those used in conventional liquid crystal displays, it may be noted that it is not essential that the thickness of the spacers be exactly the same as the thickness of the electrophoretic medium when no pressure is applied thereto. The thickness of the spacers may be slightly less than the thickness of the medium so that, when the medium is not under pressure, its thickness is determined by the capsules, but as the pressure thereon is increased and the capsules deform slightly, the layers on either side of the medium come into contact with the spacers, the spacers relieve the stress on the capsules, thereby preventing this stress building up to a level at which capsule

rupture may occur. For example, in a typical application in which the layer of capsules forming the electrophoretic medium has the form of a lamina having a thickness substantially less than its other two dimensions, the dimension of the spacers parallel to the thickness of the lamina may be from about 0.9 to about 1.0 times this thickness, although a spacer dimension close to 1.0 times this thickness is preferred. For example, if the capsules are 100 μm in diameter, the spacers may have the form of glass spheres 100 μm or slightly less in diameter.

The spacers used in the present invention may be formed from any material capable of providing the necessary stress relief to the capsules when pressure is applied to the electrophoretic medium; it will be appreciated that the choice of spacer material may vary depending upon the application in which the medium is to be employed and thus the type and magnitude of pressures to which the capsules will be exposed. Thus, the spacers may be formed from a rigid material, for example glass, or from a flexible material, for example a flexible polymer such as polyethylene, provided that the material is not so flexible that it fails to provide the necessary stress relief. Combinations of materials, for example glass spheres coated with polymer, may also be used. It is generally preferred that the spacers be formed from a substantially transparent material since colored (which term is used to include black and white) spacers may adversely affect the quality of the image produced by an electrophoretic display.

The spacers may have a variety of shapes; for example, each of the spacers may have substantially the form of a sphere, rod, cone, pyramid, cone or a frustum of a cone or pyramid. Mixtures of spacers of differing shapes may also be used.

The ratio of spacers to capsules in the present electrophoretic medium may vary widely, depending upon the intended application of the medium. This ratio is, at least in part, a compromise between two competing considerations. If too few spacers are used, certain capsules not close to a spacer may be exposed to undesirable

stress levels. On the other hand, since the spacers cannot undergo the changes in optical characteristics which the capsules undergo, the spacers may tend to introduce artifacts into the image produced by the display, and the risk of such artifacts becoming noticeable increases with the number of spacers used. In general, the ratio of spacers to capsules will be in the range of from 1:100 to 1:1,000,000, and preferably in the range of 1:1,000 to 1:100,000.

To form an electrophoretic display, the encapsulated electrophoretic medium of the present invention will typically be provided with first and second electrodes disposed on opposed sides of the medium, at least one of the first and second electrodes being light transmissive. The electrophoretic display may also comprise first and second substrates disposed on opposed sides of the electrophoretic medium, these first and second substrates being secured to the first and second electrodes respectively; typically, the first and second electrodes are formed on their respective substrates by any convenient type of printing or coating process.

In one form of such a display, the first and second electrodes and the first and second substrates are all flexible, so that the entire display is flexible. Such a display can be made paper-thin so as to resemble a conventional poster or leaf of a book. The provision of spacers in such a display may be useful to prevent damage to the display if a portion of the display is curved very sharply, as may happen, for example, if the display is being manually manipulated to fit it into a frame or similar structure.

Another form of such a display includes a touch sensing means disposed on the opposed side of one of the first and second electrodes from the electrophoretic medium, so that the display functions as a touch screen. As is well-known to those skilled in the relevant art, the touch sensing means of a touch screen typically comprises two continuous orthogonal electrodes on two separate transparent substrates, these continuous electrodes acting as an analog voltage divider. Alternatively, such a touch sensing means may comprise two arrays of transparent electrodes on separate

transparent substrates, for example, a series of parallel row electrodes on one substrate and a series of parallel column electrodes on the other, or a matrix array of electrodes on one substrate and a single continuous electrode on the other. In all cases, the two electrodes or arrays of electrodes lie parallel to one another but are spaced a short distance apart by mechanical spacers, a liquid film or pressurized gas. At least the front substrate (that adjacent the user) is made flexible so that application of modest pressure, as from a user's finger on the front substrate, will cause contact between the electrodes (or between at least one electrode in each array), thus enabling associated electronics to generate a signal indicating where on the sensing means the pressure was applied. The touch sensing means is affixed to a screen (typically the screen of a cathode ray tube, or much less commonly that of a liquid crystal display) on which images are formed, so that the user appears to be touching the image on the screen.

Encapsulated electrophoretic displays have substantial advantages over both cathode ray tubes and liquid crystal displays in touch screens. Both cathode ray tubes and conventional liquid crystal displays operate in emission (the liquid crystal displays being back-lit) so that their images become difficult to read in strong sunlight, for example when a drive-up automatic teller machine (ATM) is placed outside a bank. In contrast, electrophoretic displays operate by reflection, so they are readily readable even under the strongest light. Also, electrophoretic displays are much less bulky than cathode ray tubes, an important consideration in ATM's.

Although the pressure generated by a user's finger pressing upon a touch screen is relatively small, a user may accidentally hit the screen more sharply that intended, or hit it with a fingernail, finger ring, watch band, bracelet or the like which may generate pressures much greater than simple pressure with a finger tip. Accordingly, electrophoretic displays used in touch screens may advantageously incorporate spacers in accordance with the present invention to prevent damage to the display when substantial pressure is exerted thereon.

Although a touch screen itself requires two electrodes and the electrophoretic display also requires two electrodes, in some cases (depending upon the type of touch sensing means used) it may be possible to reduce the complexity and expense of a touch screen with an electrophoretic display by using only three electrodes. If the rear electrode of the touch screen is fabricated upon a very thin substrate, it may be possible to use this electrode as both the rear electrode of the touch screen and the front electrode of the electrophoretic display; such a dual-function electrode may conveniently be of the continuous electrode type (i.e., in the form of a single electrode extending across the entire area of the touch screen display). Alternatively a single substrate, preferably a flexible plastic film, could be coated on both sides with a continuous layer of conductive material so that this coated substrate serves as both the rear electrode of the touch screen and the front electrode of the electrophoretic display.

Another application of the present invention may be providing encapsulated electrophoretic media which can be laminated under a wider range of conditions than similar prior art media. As already mentioned, in the preparation of an encapsulated electrophoretic display it is common practice to form an electrode on a substrate and then to laminate this substrate/electrode combination to an encapsulated electrophoretic medium coated on a different substrate. This lamination is normally conducted using both heat and pressure, and this combination of heat and pressure can impose substantial stress on the capsules, because in addition to the external pressure imposed by the laminator, the capsules are subject to an internal pressure caused by the thermal expansion of the electrophoretic fluid within the capsules. By providing the electrophoretic medium with spacers in accordance with the present invention, the stresses imposed upon the capsules during the lamination can be reduced, thus widening the range of pressure and/or temperature which can be used. Since the choice of lamination adhesives is limited largely by the temperatures and pressures which can be employed in the lamination, widening the allowable pressure and temperature ranges broadens the range of useable lamination adhesives, and may thus permit the use of

adhesives having certain desirable properties (for example, increased durability) which would not otherwise be useable with the electrophoretic medium.

In some embodiments of the present invention, the spacers will be discrete entities which are mixed among the capsules either before or after the capsules are formed into the capsule layer, as described in more detail below. However, at least some of the spacers may also be secured to, or integral with, one of the electrodes or the substrates of the electrophoretic display. For example, if one or both of the substrates has the form of a flexible plastic film, such a film could bear projection or ridges which could act as spacers. Such projections or ridges could useful taper towards the viewing surface of the display; for example projections on a rear substrate could be frusto-conical or frusto-pyramidal in shape so that when the substrate is printed or coated with the layer of capsules, the capsules will overlay the outer parts of the broad base of the projections or ridges, leaving only the relatively narrow tops of the projections exposed in the final display, thus reducing the possibility of the projections introducing visible artifacts into the image provided by the display.

The exact method used to incorporate the spacers into the capsule layer may vary, and the optimum method may vary depending upon the number and type of spacers employed. As already mentioned, typically the capsule layer is rendered coherent by the provision of a binder, which lies between the capsules and binds them together. The capsule layer is formed by printing or coating a mixture of the capsules in the binder on to the surface of a substrate; conveniently, a conductive coating is provided on the substrate prior to the printing or coating so that this conductive coating can act as one of the electrodes of the final display. In one method of forming a spacing-containing capsule layer, the spacers are admixed with the capsules and the binder, and the resultant mixture is printed or coated on to the surface of the substrate. This method is especially suitable for spacers (for example, polymeric spacers) which have a density similar to that of the capsule/binder mixture. In a second method, the usual mixture of capsules and binder is first coated on to the surface of the substrate and

thereafter the spacers are dispersed among the capsules. In either method, typically, after the spacer-containing layer of capsules has been formed on the substrate, a second substrate is laminated to the layer of capsules so that the two substrates lie on opposed sides of this layer. This second substrate may bear a conductive layer which acts as the second electrode of the final electrophoretic display.

Although reference has been made throughout the foregoing description to capsules and a binder in a manner which suggests that the encapsulated electrophoretic medium of the present invention comprises a plurality of discrete capsules (and the accompanying drawings illustrate this form of the invention), the present medium may also have the form of a "polymer-dispersed electrophoretic display", hereafter abbreviated "PDED". Essentially, a PDED is a two-phase system having a discontinuous phase, which comprises a plurality of discrete droplets of an electrophoretic fluid (as usual, comprising a liquid and at least one particle disposed within the liquid and capable of moving therethrough on application of an electric field to the liquid), and a continuous phase of a polymeric material. The discrete droplets of electrophoretic fluid within a PDED may be referred to as capsules or microcapsules even though no discrete capsule membrane is associated with each individual droplet. Accordingly, references to "capsules" herein are to be construed as extending to PDED's, which are considered to be subsets of encapsulated electrophoretic displays.

Embodiments of the invention will now be described, though by way of illustration only, with reference to the accompanying drawings which, as already stated, show schematic cross-sections through three different encapsulated electrophoretic displays of the present invention, these cross-sections being taken perpendicular to the plane of the electrodes of the displays.

Figure 1 of the accompanying drawings shows an encapsulated electrophoretic display (generally designated 100) of the present invention. This display comprises a transparent front substrate 102 coated with a continuous transparent front electrode 104 which may, for example, be formed from indium tin oxide (ITO).

The exposed (outer) surface 106 (the top surface as illustrated in Figure 1) of the front substrate 102 acts as a viewing surface through which an observer views the display 100; if, for example, the display 100 is to be used as part of a touch screen display, the touch sensing means of the display would be mounted on the surface 106. The display 100 further comprises a rear substrate 108 coated with a plurality of discrete rear electrodes 110, which define individual pixels of the display 100; only two of the rear electrodes 110 are shown in Figure 1. Between the electrodes 104 and 110 are disposed a plurality of microcapsules (generally designated 112); each of these microcapsules comprises a capsule wall enclosing a colored liquid 114 in which are suspended charged colored particles 116 of a color different from the that of the liquid 114. For ease of illustration, the microcapsules 112 are shown as spherical in the Figures, although in practice it is preferred that they be of the non-spherical shapes described in commonly-owned U.S. Patent No. 6,067,185. The microcapsules 112 are sufficient, by themselves, to maintain the spacing between the electrodes 104 and 110. However, for reasons already explained above, there are dispersed among the microcapsules 112 a plurality of spacers 118 (only one of which is shown in Figure 1) having the form of glass spheres of a diameter essentially the same as that of the microcapsules 112.

As previously mentioned, the individual microcapsules 112 are normally bound to each other and to the electrodes 104 and 110 by a polymeric binder. This binder is omitted from Figures 1, 2 and 3 for ease of illustration and comprehension.

Figure 2 illustrates a second encapsulated electrophoretic display (generally designated 200) of the present invention; this display 200 closely resembles the display 100 shown in Figure 1, except that the spherical spacers 118 are replaced by cylindrical rod spacers 218, only one of which is shown in Figure 2. The spacers 218 may be formed of glass. polymer or other materials.

Figure 3 illustrates a third encapsulated electrophoretic display (generally designated 300) of the present invention; this display 300 closely resembles the displays 100 and 200 shown in Figures 1 and 2 respectively, except that the spacers

118 and 218 are replaced by frusto-conical spacers 318 (only one of which is shown in Figure 3), which are integral with the rear substrate 108. It should be noted that the microcapsules 112 on either side of the spacer 318 overlap part of the base of the spacer, thus reducing the risk that the spacer 318 will introduce any visible artifact into the display 300. Also, it should be noted that the upper end (in Figure 3) of the spacer 318 is spaced slightly from the front electrode 104, thus allowing the front substrate 102, the front electrode 104 and the microcapsules 112 to deform slightly before the front electrode 104 contacts the spacer 318.

Apart from the use of spacers, the encapsulated electrophoretic displays of the present invention resemble prior art encapsulated electrophoretic displays, and hence the present displays can make use of any known materials and processes for the production of such displays, as described, for example, in U.S. Patents Nos. 6,017,584 and 6,067,185, and in copending commonly-assigned Application Serial No. 09/413,444, filed October 6, 1999, and the corresponding International Application PCT/US99/23313 (Publication No. WO 00/20922); the entire disclosures of all these patents and applications are herein incorporated by reference. Accordingly, the reader is referred to these patents and applications for details of such materials and processes.

The following Examples are now given, though by way of illustration only, to show preferred materials, conditions and methods which may be useful in the preparation of the electrophoretic medium of the present invention.

1. Example 1

The following procedure describes gelatin/acacia microencapsulation for use in electrophoretic displays of the present invention.

a. Preparation of Oil (Internal) Phase

To a 1L flask is added 0.5 g of Oil Blue N (Aldrich, Milwaukee, WI), 0.5 g of Sudan Red 7B (Aldrich), 417.25 g of Halogenated Hydrocarbon Oil 0.8 (Halogenated hydrocarbon Products Corp., River Edge, NJ), and 73.67 g of Isopar-G® (Exxon, Houston, TX). The mixture is stirred at 60°C for six hours and is then cooled

to room temperature. 50.13 g of the resulting solution is placed in a 50 mL polypropylene centrifuge tube, to which is added 1.8 g of titanium dioxide (TiO_2) (du Pont), 0.78 g of a 10% solution of OLOA 1200 (Chevron, Somerset, NJ), in Halogenated Hydrocarbon Oil 0.8, and 0.15 g of Span 85 (Aldrich). This mixture is then sonicated for five minutes at power 9 in an Aquasonic Model 75D sonicator (VWR, Westchester, PA) at 30°C.

b. Preparation of Aqueous Phase

10.0 g of acacia (Aldrich) is dissolved in 100.0 g of water with stirring at room temperature for 30 minutes. The resulting mixture is decanted into two 50 mL polypropylene centrifuge tubes and centrifuged at about 2000 rpm for 10 minutes to remove insoluble material. 66 g of the purified solution is then decanted into a 500 mL non-baffled jacketed reactor, and the solution is then heated to 40°C. A six-blade (vertical geometry) paddle agitator is then placed just beneath the surface of the liquid. While agitating the solution at 200 rpm, 6 g of gelatin (300 bloom, type A, Aldrich) is carefully added over about 20 seconds in order to avoid lumps. Agitation is then reduced to 50 rpm to reduce foaming. The resulting solution is then stirred for 30 minutes.

c. Encapsulation

With agitation at 200 rpm, the oil phase, prepared as described above, is slowly poured over about 15 seconds into the aqueous phase, also prepared as described above. The resulting oil/water emulsion is allowed to emulsify for 20 minutes. To this emulsion is slowly added over about 20 seconds 200 g of water that has been preheated to 40°C. The pH is then reduced to 4.4 over five minutes with a 10% acetic acid solution (acetic acid from Aldrich). The pH is monitored using a pH meter that was previously calibrated with pH 7.0 and pH 4.0 buffer solutions. The resultant mixture is stirred for 40 minutes. 150 g of water that has been preheated to 40°C are then added, and the contents of the reactor are then cooled to 10°C. When the solution temperature

reaches 10°C, 3.0 mL of a 37% formalin solution (Aldrich) is added, and the solution is further stirred for another 60 minutes. 20 g of sodium carboxymethylcellulose (NaCMC) is added, and the pH is then raised to 10.0 by the addition of a 20 wt. % solution of sodium hydroxide (NaOH). The thermostat bath is then set to 40°C and allowed to stir for another 70 minutes. The slurry is allowed to cool to room temperature overnight with stirring. The resulting capsule slurry is then ready to be sieved.

d. Formation of Display

Two procedures believed to be appropriate for preparing an electrophoretic display of the present invention from the above capsule slurry are described below.

i. Procedure using a urethane binder

The resulting capsule slurry from above is mixed with the aqueous urethane binder NeoRez R-9320 (Zeneca Resins, Wilmington, MA) at a ratio of one part binder to 10 parts capsules. To provide spacers, 100 μm glass spheres are also mixed into the slurry binder mixture at a ratio of one spacer to 10,000 capsules. The resulting mixture is then coated using a doctor blade in an approximately 100-125 μm thick sheet of indium-tin oxide sputtered polyester film. The blade gap of the doctor blade is controlled at 0.18 mm so as to lay down a single layer of capsules. The coated film is then dried in hot air (60°C) for 30 minutes. After drying, the dried film is hot laminated at 60°C to a backplane comprising an approximately 100-25 μm thick sheet of polyester screen printed with thick film silver and dielectric inks with a pressure of 15 psi in a hot roll laminate from Cheminstruments, Fairfield, OH. The backplane is connected to the film using an anisotropic tape. The conductive areas form addressable areas of the resulting display.

ii. Procedure using a urethane/polyvinyl alcohol binder

The resulting capsule slurry from above is mixed with the aqueous binder comprising a mixture of NeoRez R-966 (Zeneca Resins) and a 20% solution of Airvol 203 (a poly(vinyl alcohol), Airvol Industries, Allentown, PA) at a ratio of one part Airvol 203 solution to one part NeoRez R-966 to five parts capsules. To provide spacers, 100 μm glass spheres are also mixed into the slurry binder mixture at a ratio of one spacer to 10,000 capsules. The resulting mixture is then coated using a doctor blade in an approximately 100-125 μm thick sheet of indium-tin oxide sputtered polyester film. The blade gap of the doctor blade is controlled at 0.18 mm so as to lay down a single layer of capsules. The coated film is then dried in hot air (60°C) for 30 minutes. After drying, a thick film silver ink is then printed directly onto the back of the dried film and allowed to cure at 60°C. The conductive areas form the addressable areas of the display.

2. Example 2

The following is an example of the preparation of microcapsules by *in situ* polymerization.

In a 500 mL non-baffled jacketed reactor is mixed 50 mL of a 10 wt. % aqueous solution of ethylene co-maleic anhydride (Aldrich), 100 mL water, 0.5 g resorcinol (Aldrich), and 5.0 g urea (Aldrich). The mixture is stirred at 200 rpm and the pH adjusted to 3.5 with a 25 wt. % NaOH solution over a period of 1 minute. The pH is monitored using a pH meter that was previously calibrated with pH 7.0 and pH 4.0 buffer solutions. To this is slowly added the oil phase, prepared as described above in Ex. 1, and agitation is increased to 450 rpm to reduce the average particle size to less than 200 μm. 12.5 g of a 37 wt. % aqueous formaldehyde solution is then added and the temperature raised to 55°C. The solution is heated at 55°C for two hours.

3. Example 3

The following is an example of the preparation of microcapsules by interfacial polymerization.

To 44 g of the oil phase, prepared as described above in Example 1, is added 1.0 g of sebacoyl chloride (Aldrich). Three milliliters of the mixture are then dispersed in 200 mL of water with stirring at 300 rpm at room temperature. To this dispersion is then added 2.5 mL of a 10 wt. % aqueous solution of 1,6-diaminohexane. Capsules form after about one hour.

Like other encapsulated electrophoretic displays, the encapsulated electrophoretic displays of the present invention provide flexible, reflective displays that can be manufactured easily and consume little power (or no power in the case of bistable displays in certain states). Such displays, therefore, can be incorporated into a variety of applications and can take on many forms. Once the electric field is removed, the electrophoretic particles can be generally stable. Additionally, providing a subsequent electric charge can alter a prior configuration of particles. Such displays may include, for example, a plurality of anisotropic particles and a plurality of second particles in a suspending fluid. Application of a first electric field may cause the anisotropic particles to assume a specific orientation and present an optical property. Application of a second electric field may then cause the plurality of second particles to translate, thereby disorienting the anisotropic particles and disturbing the optical property. Alternatively, the orientation of the anisotropic particles may allow easier translation of the plurality of second particles. Alternatively or in addition, the particles may have a refractive index that substantially matches the refractive index of the suspending fluid.

As already mentioned, an encapsulated electrophoretic display can be constructed so that the optical state of the display is stable for some length of time. When the display has two states that are stable in this manner, the display is bistable, within the meaning of that term as previously defined; if more than two states of the

display are stable, then the display is multistable. However, whether a display is effectively bistable state depends upon the display's application. A slowly decaying optical state can be effectively bistable if the optical state is substantially unchanged over the required viewing time. For example, in a display that is updated every few minutes, a display image that is stable for hours or days is effectively bistable for a particular application. Alternatively, it is possible to construct encapsulated electrophoretic displays in which the image decays quickly once the addressing voltage to the display is removed (i.e., the display is not bistable or multistable). Whether or not an encapsulated electrophoretic display is bistable, and its degree of bistability, can be controlled through appropriate chemical modification of the electrophoretic particles, the suspending fluid, the capsule, and binder materials.

An encapsulated electrophoretic display may take many forms. The capsules of such a display may be of any size or shape. The capsules may, for example, be spherical and may have diameters in the millimeter range or the micron range, but are preferably from about ten to about a few hundred microns. The particles within the capsules of such a display may be colored, luminescent, light-absorbing or transparent, for example.

From the foregoing description, it will be seen that the encapsulated electrophoretic media and displays of the present invention preserve all the advantages of prior art encapsulated electrophoretic media and displays, while rendering the encapsulated electrophoretic medium less susceptible to damage from pressure exerted upon the medium. Thus, the media and displays of the present invention may be useful in applications where prior art encapsulated electrophoretic media and displays cannot be used because of their susceptibility to pressure damage.

H-309PC

CLAIMS

1. An encapsulated electrophoretic medium comprising a layer of capsules (112), each of these capsules (112) comprising a liquid (114) and at least one particle (116) disposed within the liquid (114) and capable of moving therethrough on application of an electric field to the medium, the medium being characterized by a plurality of spacers (118; 218; 318) dispersed among the capsules (112).

2. A medium according to claim 1 characterized in that at least one of the spacers (118; 218; 318) has substantially the form of a sphere or a rod.

3. A medium according to either of the preceding claims characterized in that the spacers (118; 218; 318) are formed from glass and/or a polymeric material.

4. A medium according to any one of the preceding claims characterized in that the spacers (118; 218; 318) are formed from a substantially transparent material.

5. A medium according to any one of the preceding claims characterized in that the ratio of spacers (118; 218; 318) to capsules (112) is in the range of from 1:100 to 1:1,000,000.

6. A medium according to claim 5 wherein the ratio of spacers (118; 218; 318) to capsules (112) is in the range of from 1:1,000 to 1:100,000.

7. A medium according any one of the preceding claims characterized in that the layer of capsules (112) has the form of a lamina having a thickness substantially less than its other two dimensions, and wherein the dimension of the spacers (118; 218; 318) parallel to the thickness of the lamina is from 0.9 to 1.0 times this thickness.

8. An electrophoretic display (100; 200; 300) comprising an encapsulated electrophoretic medium according to any one of the preceding claims in combination with first (104) and second (110) electrodes disposed on opposed sides of

the electrophoretic medium, at least one of the first (104) and second (110) electrodes being light transmissive.

9. An electrophoretic display according to claim 8 characterized by first (102) and second (108) substrates disposed on opposed sides of the electrophoretic medium, the first (102) and second (108) substrates being secured to the first (104) and second (110) electrodes respectively.

10. An electrophoretic display according to claim 9 characterized in that the first (104) and second (110) electrodes and the first (102) and second (108) substrates are all flexible.

11. An electrophoretic display according to any one of claims 8 to 10 characterized by touch sensing means disposed on the opposed side of one of the first (104) and second (110) electrodes from the electrophoretic medium.

12. An electrophoretic display according to any one of claims 8 to 11 characterized in that at least one of the spacers (118; 218; 318) is secured to, or integral with, one of the first (104) and second (110) electrodes, or one of the first (102) and second (108) substrates.

13. A method of forming an electrophoretic display (100; 200; 300) on a substrate, the method comprising providing, adjacent the substrate, an encapsulated electrophoretic medium comprising a layer of capsules (112), each of these capsules comprising a liquid (114) and at least one particle (116) disposed within the liquid (114) and capable of moving therethrough on application of an electric field to the medium, the method being characterized by incorporating a plurality of spacers (118; 218; 318) among the capsules (112).

14. A method according to claim 13 characterized in that a mixture of the capsules (112) and the spacers (118; 218; 318) is formed in a binder, and this mixture is coated on to the surface of the substrate.

15. A method according to claim 13 characterized in that a mixture of the capsules (112) with a binder is coated on to the surface of the substrate, and the spacers (118; 218; 318) are dispersed among the capsules (112).

16. A method according to any one of claims 13 to 15 characterized by laminating a second substrate to the layer of capsules (112) so that the two substrates (102, 108) lie on opposed sides of this layer.

17. A method according to any one of claims 13 to 16 characterized in that the substrate, or at least one of the substrates, bears a conductive coating (104, 110).

18. A method according to any one of claims 13 to 17 characterized by any one or more of the features defined in claims 2 to 12.

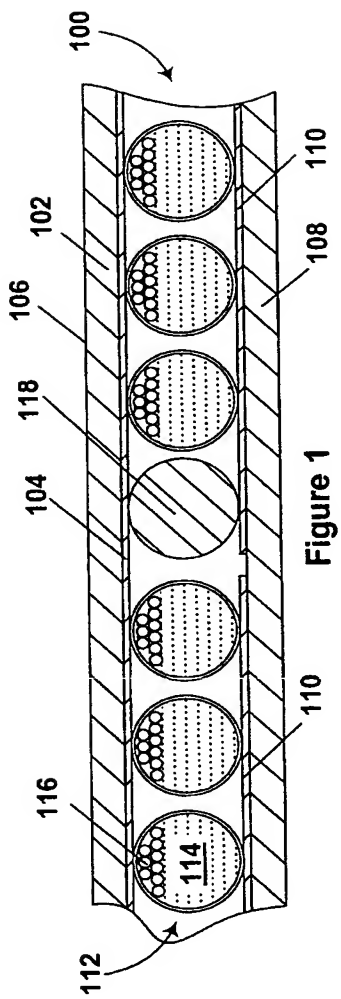

Figure 1

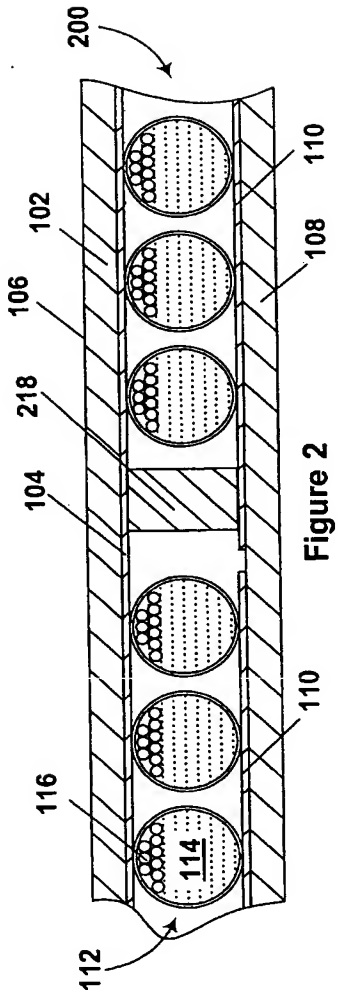

Figure 2

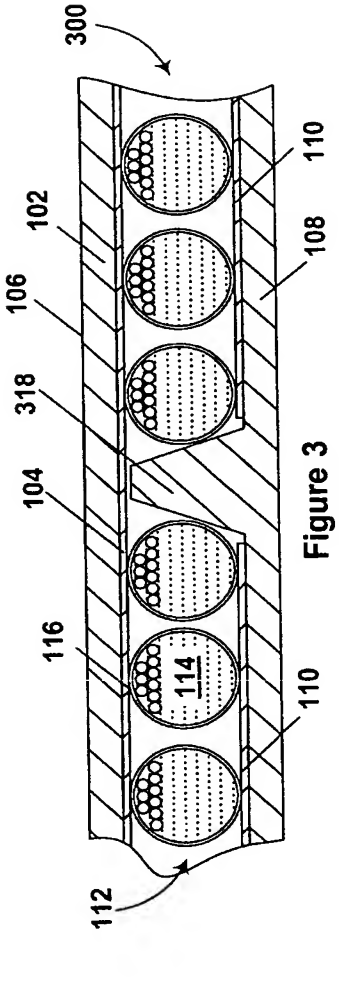

Figure 3